A Novel Multi-frequency Downconverter for 13 cm EME

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EME operation on the 13 cm band is probably more awkward than on any other band, owing to the different allocations worldwide where transmitting can take place. To the author's knowledge 2302, 2304, 2320 and 2424 MHz are used. Not only does this stretch the bandwidth of the feedhorn, but it also leads to a lot of extra receive equipment to handle all the options available. In preparing to become operational on 13 cm, and to avoid these complications, a downconverter has been developed which can be switched to any of four frequencies by two logic lines, and requires no extra mixers, switched filters etc.

Design Concept

The key part of the downconverter is a synthesized local oscillator, using a PIC with two control lines control to generate the loading commands for the different LO frequencies required. The VCO control voltage is also used to adjust the frequency of a tuneable image rejection filter, and in this way the downconverter can be used anywhere within the 2.3-2.45GHz band.

A block diagram of the downconverter is shown in Figure 1.

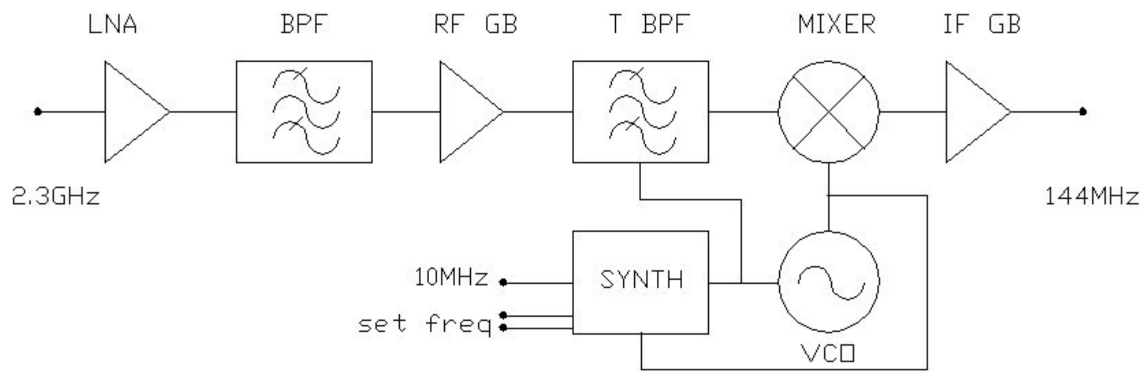

Figure 1: Block diagram of multi-frequency 13 cm downconverter

The RF input signal is amplified by an LNA stage using a MGF4919G device in the well-known DJ9BV circuit. This is followed by a fixed-tuned bandpass filter using coupled resonator microstrip lines, with sufficient bandwidth to cover the whole band. This filter provides some image rejection (19 dB at 2302 MHz reducing to 15.5 dB at 2424 MHz). The signal is amplified further by an ABA52563 gain block and then mixed down to 144 MHz by a ring mixer using a pair of HP2835 diodes. The IF output from the mixer is fed via a quarter-wave trap to filter out any LO leakage to the IF amplifier, which is another ABA52563.

Tuneable Filter and VCO

The tuneable filter and VCO are based on similar microstrip circuit elements.

Filter

This filter also uses coupled microstrip elements, but incorporates series varicap diodes within the microstrip elements to tune the centre frequency of the filter from 2300 to 2450 MHz. A photo of the tuned filter is shown in Figure 2. All filters are covered with a brass shield.

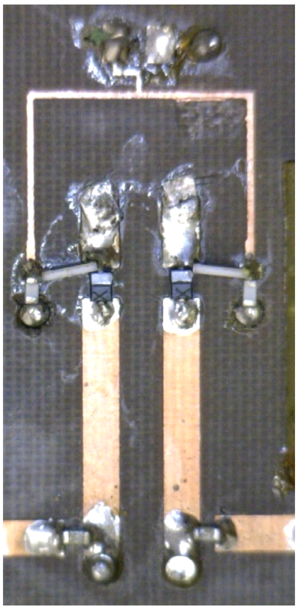

Figure 2: Tuneable image rejection filter

The RF input/output microstrip lines are near the bottom of the photo, connected close to the grounded ends of the tuned lines using DC blocking capacitors. The varicap diodes are located in series with the tuned lines, about three-quarters of the way up towards the ‘hot’ end. The diodes are biased via 100 kΩ 1206 resistors, mounted on edge to reduce stray capacitance to ground.

With the varicaps at maximum capacitance (0V applied) the resonant frequency of the filter is largely determined by the total length of the coupled microstrip lines, as the diodes behave more-or-less like short circuits. As the bias voltage is raised and the diodes’ capacitance reduces, the effective length of the lines beyond the diodes becomes shorter and the centre frequency of the filter increases.

The filter was designed using the method described in Appendix 1. The spacing between the lines was set to give a good compromise between 3 dB bandwidth and image rejection, and the positions of the diodes along the lines were adjusted to give sufficient tuning range and acceptable loss. Positioning the diodes closer to the open ‘hot’ ends of the lines reduces the loss, but also reduces the tuning range.

The final design of the filter had a tuning range of 175 MHz with a varicap tuning voltage of 0 to 8 V, and provided an image rejection of 20 dB minimum. Loss varied from 7 dB at 2302 MHz to 5 dB at 2424.

VCO

The VCO is a modified version of a design by S53MV [1]. The oscillator consists of an amplifier using a bipolar transistor and some simple matching elements to obtain approximately 10 dB gain at the operating frequency. The output of the amplifier is coupled back to its input via a tuneable filter similar to that used in the image rejection filter, together with phase delay elements to ensure that the total phase shift around the loop is 360 degrees.

By using the same filter design as the image rejection filter (moved downward in frequency by 144 MHz) the frequency of the oscillator tracks the frequency of the tuneable filter sufficiently closely. A plot of the centre frequency of the image filter and the VCO is shown in Figure 3.

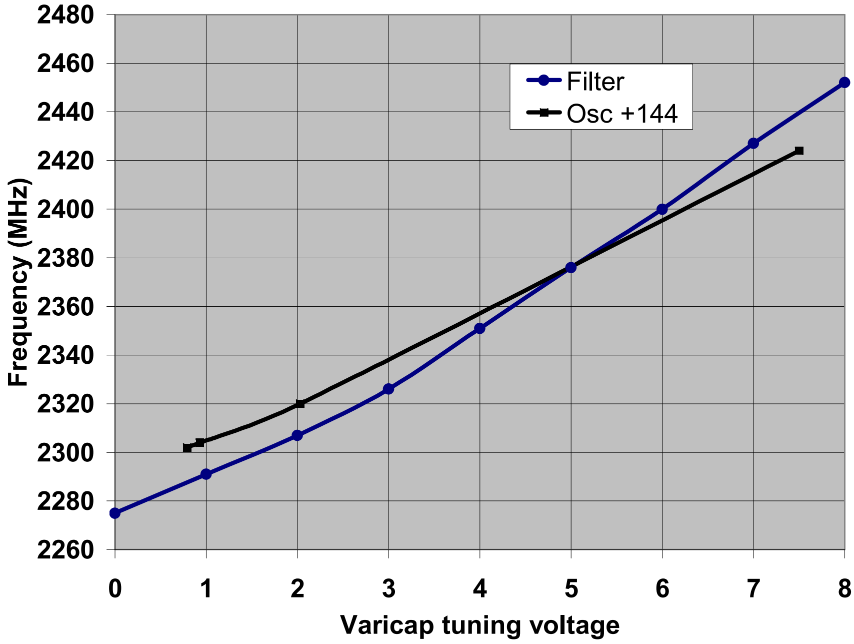

Figure 3: Tracking between filter centre frequency and VCO frequency

The worst case tracking error was about 18 MHz, which was considered to be sufficiently small compared to the 3 dB bandwidth of the tuneable image filter (about 90 MHz). A photograph of the VCO is shown in Figure 4. This design of VCO has been used successfully for multiplication to 24GHz, so certainly has more than adequate phase noise for use at 13 cm!

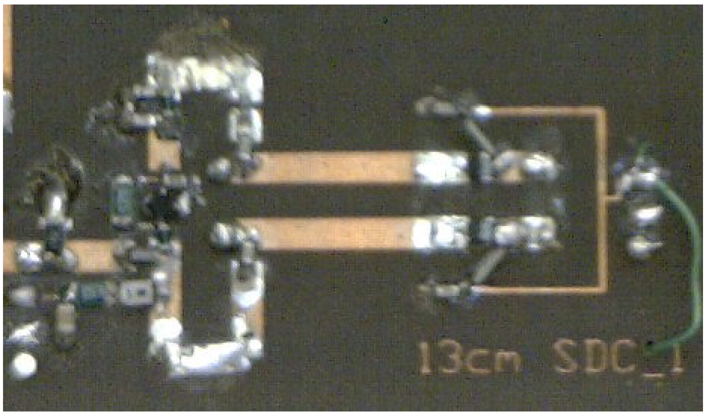

Figure 4: 2158 – 2280 MHz VCO

Complete RF/IF Section

Figure 5 is the circuit diagram of the complete RF/IF section of the downconverter. All component parts were integrated onto a single 109 x 71 mm PTFE printed circuit board, with the exception of the synthesizer which was realized on a separate board, described later.

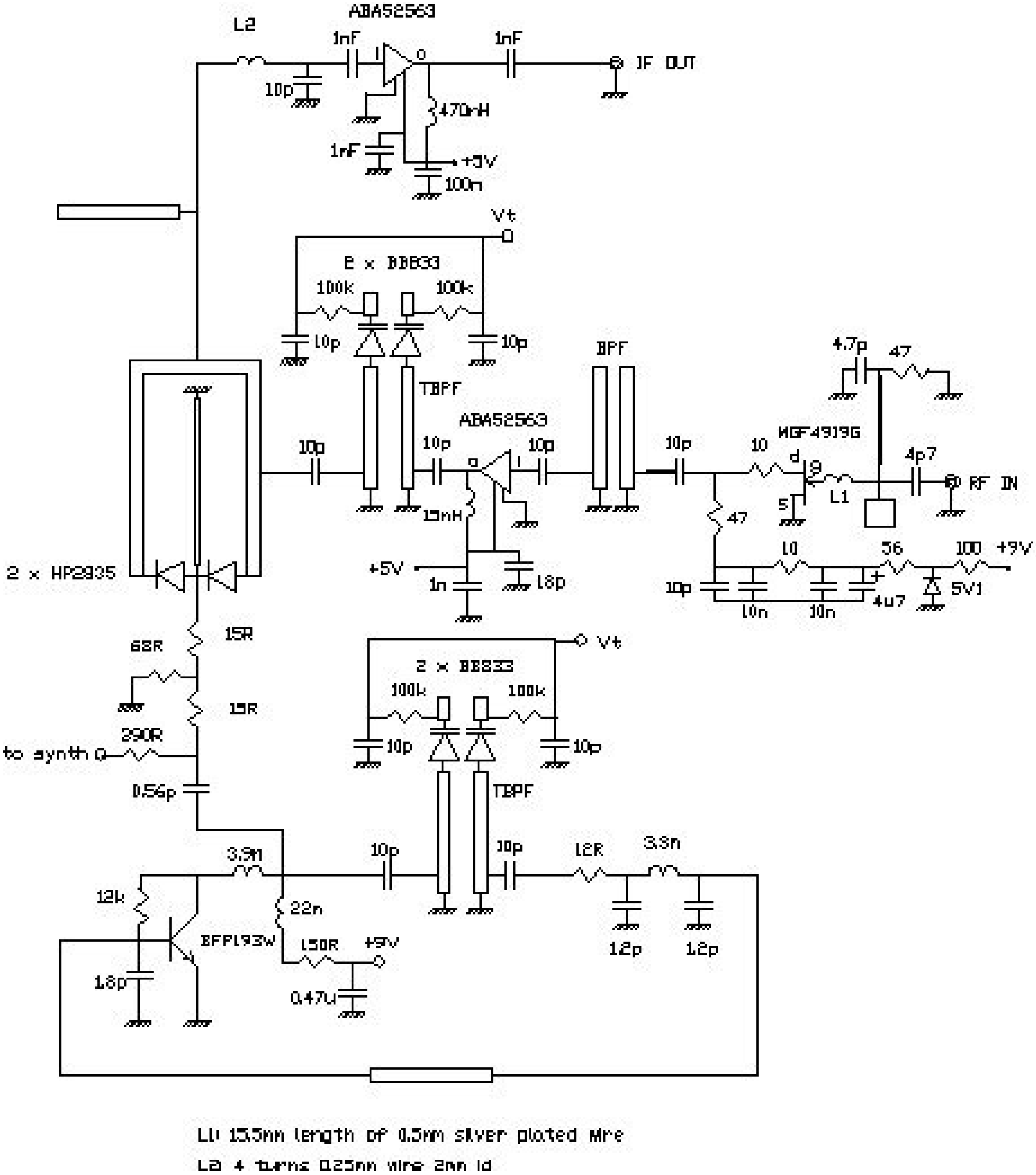

Figure 5: Circuit diagram of the RF board

Figure 6 is a photograph of the RF board (complete with necessary screening metal-work) mounted in a 30mm deep Schuberth tinplate box. The synthesizer board (described next) is mounted on the reverse side of the RF board.

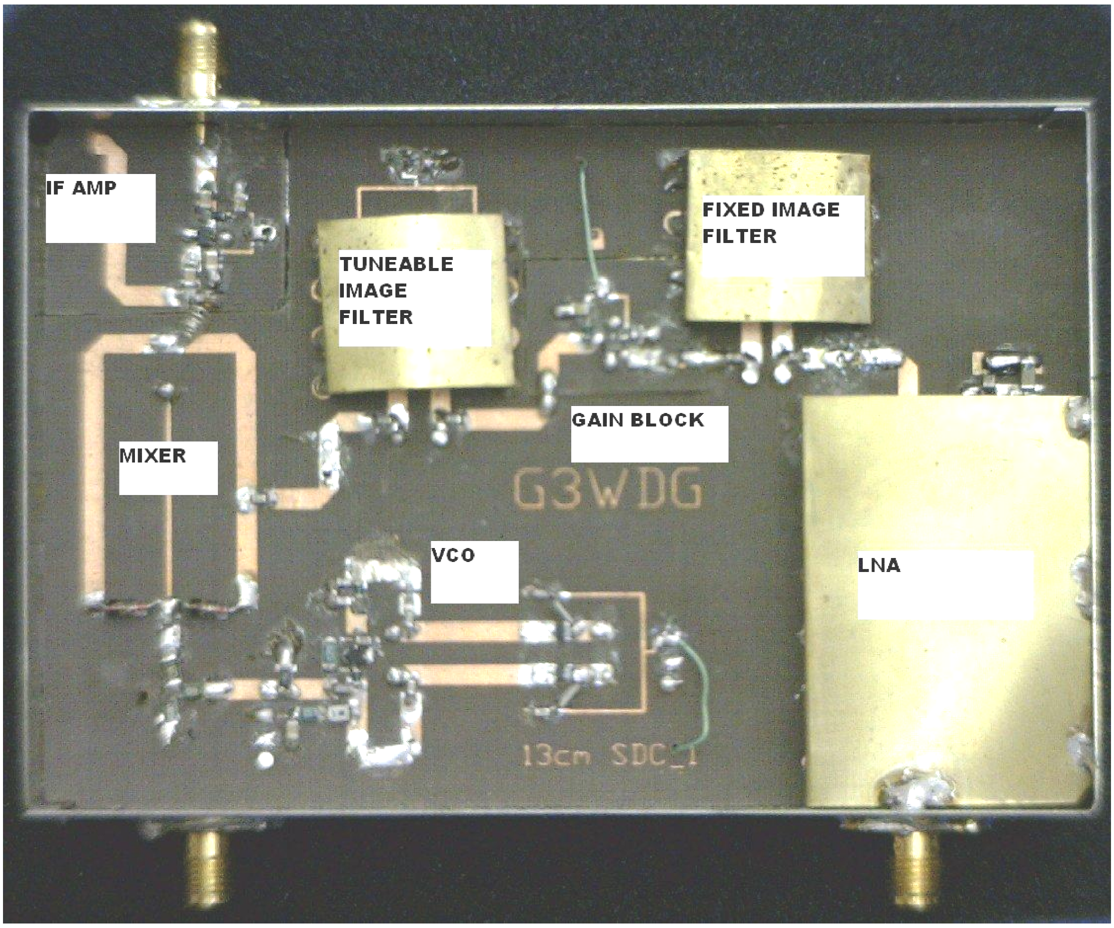

Figure 6: Complete RF section of the multi-frequency 13 cm downconverter

Synthesizer

The synthesizer is based on a design by VE1ALQ [2] and uses the LMX2326 device. This device is now obsolete, but an alternative is still available (ADF4118). The charge pump output from this device had insufficient range to tune the oscillator and image rejection filter over the required range, and a low noise x2 voltage amplifier was added to increase the voltage swing. The loop filter was designed using an on-line design tool [3].

The synthesizer chip requires a serial data input to set the operating frequency, and this proved to be an excellent motivation for me to delve into the world of PICs (with the help of our son Martin who was studying them at school at the time)! The PIC device chosen to provide the register loading commands is an “educational” type, the PICAXE 08M [4]. This device is programmed in BASIC using free software, and requires no extra hardware to program it if a serial port is available on your PC. In my opinion this is a great way to get started with PICs.

The exact serial bit stream sequences needed for the required frequencies of 2158, 2160, 2176 and 2280 MHz were determined by another free software package [5] and example PIC software can be found in reference [6].

Figure 7 is the circuit diagram of the synthesizer board, and Figure 8 shows a prototype board (except for the x2 voltage amplifier). As noted above, the synthesizer can conveniently be mounted on the rear of the RF board.

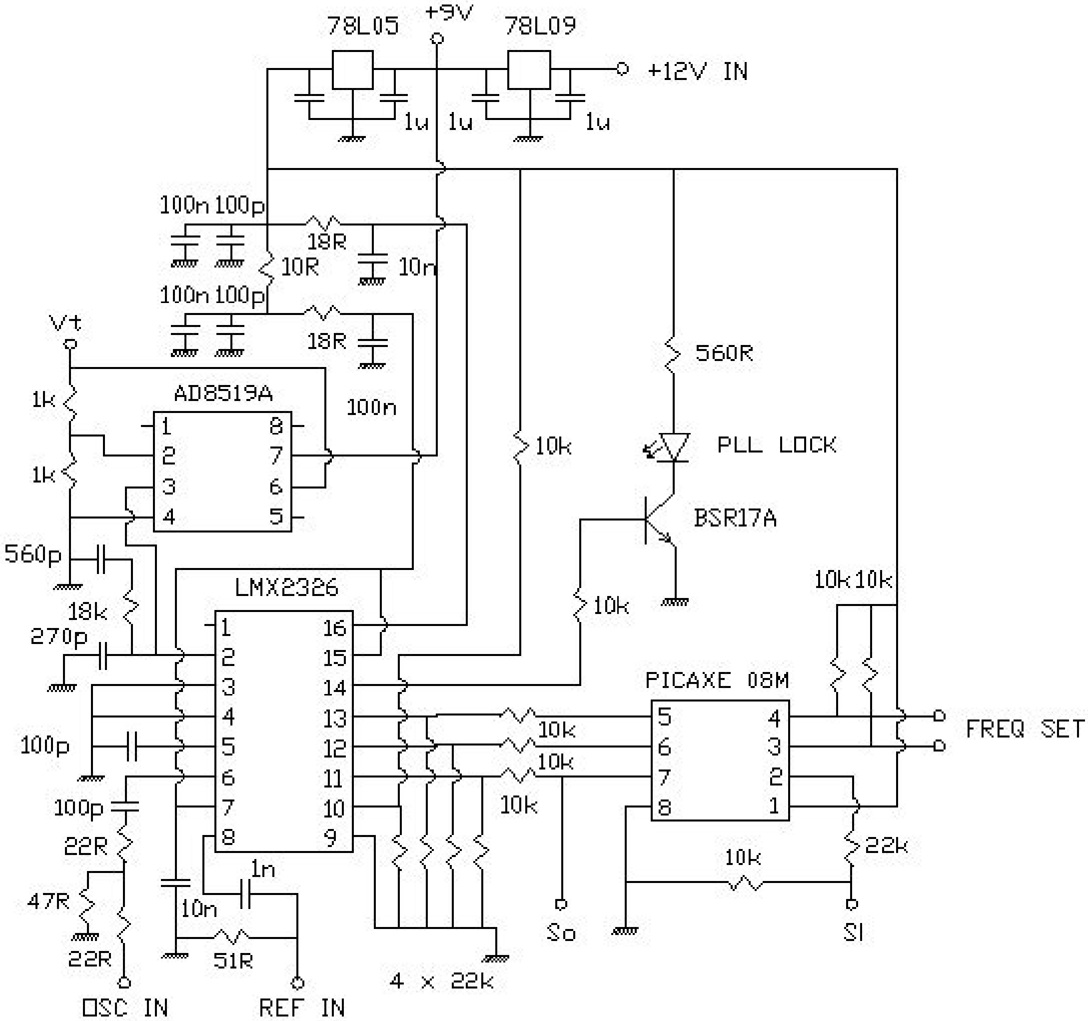

Figure 7: Circuit diagram of the synthesizer board

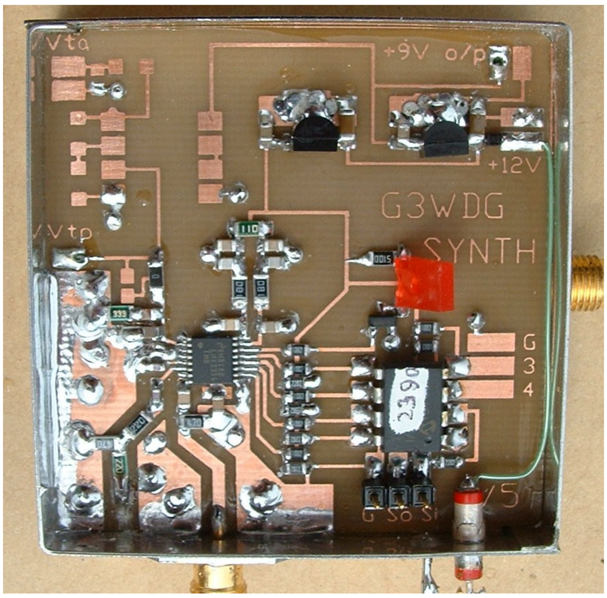

Figure 8: Boxed synthesizer using LMX2326 and PICAXE 08M

The synthesizer requires a reference frequency input, and a frequency of 10 MHz was chosen. I used a surplus ISOTEMP 134-10 high quality OCXO, which was trimmed to frequency using a beacon signal from another synthesiser that had a GPDSO reference.

Measured Performance

Frequency	Noise Figure	Conversion Gain	Image Rejection
2302 MHz	0.59 dB	45.1 dB	39.5 dB
2304 MHz	0.59 dB	45.3 dB	38.0 dB
2320 MHz	0.55 dB	46.2 dB	34.0 dB
2424 MHz	0.73 dB	43.0 dB	36.5 dB

Conclusion

This novel downconverter for 13 cm allows very simple operation on all EME frequencies. It has been used for EME reception on 2304 and 2320 MHz so far, and once a septum feed has been installed, hopefully also on 2424 MHz.

References

1. S53MV, coupled resonator design: http://lea.hamradio.si/~s53mv/spectana/vco.html
2. VE1ALQ, synthesizer design: http://www.ve1alq.com/lxm2306pll/LMX2306.htm
3. PLL design tool: http://www.ti.com/ww/en/analog/webench/easypll.shtml
4. PICKAXE data: http://www.picaxe.com
5. Synthesizer code calculator: http://www.ti.com/tool/codeloader
6. PICKAXE code for synthesizer: http://www.sucklingfamily.free-online.co.uk/synth/synthload.htm

Appendix

Coupled Resonator Microstrip Filters

Coupled resonator microstrip filters are used in three places in this design, the fixed and tuneable image filters, and as the tuneable element in the VCO. The filter consists of two coupled microstrip lines, with adjacent ends grounded and RF input and output tapped in close to the grounding points. The resonators are approximately one quarter wavelength long, allowing for the dielectric constant of the printed circuit boards. They offer adequate rejection for many applications and occupy less board area than many other designs. I have used them in the past as convenient image rejections filters [A1] and with a 144 MHz IF they offer adequate image rejection up to 3.4 GHz.

These filters can be designed reasonably well by cut and try methods, but recently electromagnetic simulation software has become available which allows them to be designed with high accuracy, such that little or no tuning is required. Some of these programs can be downloaded free of charge (eg *Sonnet Lite* [A2]) and have sufficient capability to design many items of interest to microwave radio amateurs. I have used this software package to design a number of filters, branched arm couplers and power amplifier matching circuits.

Figure A1 shows the layout of a filter similar to the fixed image rejection filter used in the downconverter.

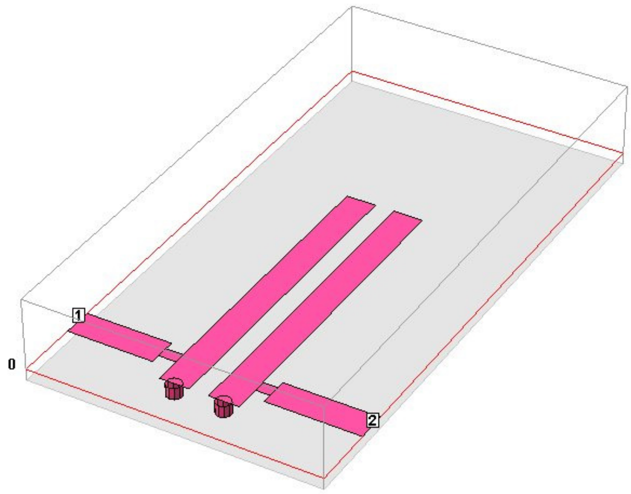

Figure A1: 3D view of coupled resonator microstrip filter

The layout editor in the software allows the user to draw the circuit initially, and later to edit features, such as:

- spacing between the lines (to adjust bandwidth)
- length of the lines (to adjust frequency)
- location of the taps (to adjust impedance matching).

For a structure of this kind, it takes the program a minute or so to compute the response, so it does not take too long to adjust the filter manually to give the desired response.

The predicted frequency response is given in Figure A2. In practice the author has found the measured response to show slightly higher loss than predicted. The centre frequency usually comes out a few tens of MHz low in frequency, so often the lines need to be trimmed slightly to get the filter exactly on frequency.

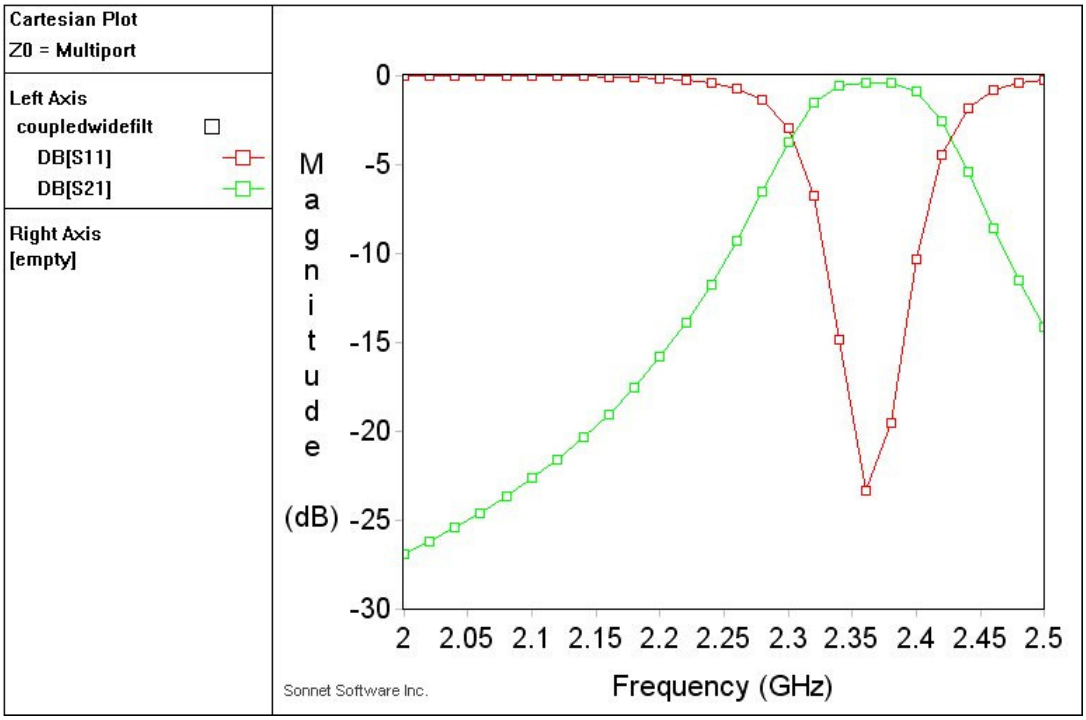

Figure 8: Predicted frequency response of the coupled microstrip filter

References

A1. http://www.g3wdg.free-online.co.uk/modes.htm

A2. http://www.sonnetsoftware.com/products/lite/